AD NUMBER

AD002493

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to DoD only; Administrative/Operational Use; 17 MAR 1952. Other requests shall be referred to Rome Air Development Center, Griffiss AFB, NY 13441-5700. Pre-dates formal DoD distribution statements. Treat as DoD only.

AUTHORITY

RL-IMPS ltr dtd 22 Feb 1995

AD-

2493

The
Antenna Laboratory

Department of Electrical Engineering

QUARTERLY PROGRESS REPORT

Effects of Type of Polarization on Echo Characteristics

Contract AF 28 (099)-90

For Period Ending 15 March 1952

ROME AIR DEVELOPMENT CENTER

Griffiss Air Force Base, Rome, New York

389-13 17 March 1952

The Ohio State University
Research Foundation
Columbus, Ohio

PROGRESS REPORT 389-13

COPY NO. 5

REPORT

by

THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION

COLUMBUS 10, OHIO

Cooperator	Rome Air Development Center Griffiss Air Force Base Rome, New York
Contract	AF 28(099)-90
Investigation of	Effects of Type of Polarization on Echo Characteristics
Subject of Report	Quarterly Progress Report Period Ending 15 March 1952
Submitted by	Antenna Laboratory Department of Electrical Engineering
Date	17 March 1952

EFFECTS OF TYPE OF POLARIZATION
ON ECHO CHARACTERISTICS

A.	ABSTRACT	1
B.	PURPOSE	1
C.	FACTUAL DATA	1
D.	CONCLUSIONS	13
E.	PROGRAM FOR NEXT INTERVAL	13
F.	BIBLIOGRAPHY	13
G.	APPENDIX	14
H.	IDENTIFICATION OF TECHNICIANS	15

EFFECTS OF TYPE OF POLARIZATION ON ECHO CHARACTERISTICS

A. ABSTRACT

Measurements of the variation in echo signal from a 1/20-scale 1
F-80 aircraft at 9000 mc are described. Improvement in pattern repetition has been obtained by increasing the angle between the line of sight and the floor surface.

Modifications of the measuring apparatus permit the transmitting 2
antenna polarization to be varied; the receiving antenna polarization remains linear. The application of this technique to scattering matrix measurements is discussed.

The effect of target symmetry on the cross-polarized linear echo 3
and circularly polarized echo is considered.

B. PURPOSE

Theoretical and experimental studies applicable to sections a, b, 4
and c of contract, entitled:

a. Optimum type of polarization for reducing the ratio of rain to 5
aircraft return.

b. Optimum type of polarization for increased echoing area of jet 6
aircraft.

c. The order of magnitude of the advantages to be expected from 7
recommended types of polarization.

C. FACTUAL DATA

As described in Progress Report 389-11,[1] the variation in echo 8
with direction of linear polarization may be utilized to determine the polarization properties of a radar target, but a high degree of accuracy must be maintained in order that the polarization response may be

found from echo measurements at a discrete number of linear polarizations. If patterns obtained with a given polarization vary from day to day, the analysis becomes a difficult task. In the past, measurements have been made with the line of sight (from the transmitting and receiving horn to the target) in a horizontal plane. This procedure simplifies the problem of model support and rotation. Extreme care was taken to align the model in the same position for each measurement as it was found that slight errors in model positioning caused significant changes in the echo pattern. Since the pattern dependence on model position was so critical, it was suspected that multiple bounce and background reflections might be affecting the echo patterns. The model was relocated higher above the floor, and the line of sight from horn to target elevated to an angle of 3.5° with the horizontal. Measurements are now being completed on the 1/20-scale model of the F-80 aircraft. Excellent repetition may be obtained with reasonable care in model alignment. Fig. 1 illustrates this repetition for two voltage patterns of the return from the model for a range of aspects about the nose in a horizontal plane. The polarization is horizontal in both cases; the patterns were taken two weeks apart. Weather conditions, particularly prevalent winds, have limited useful measuring time to a few hours per week in the past quarter, but the measurements on the 1/20-scale F-80 will be completed within a month.

Since linearly polarized echo measurements alone cannot completely 9
determine the polarization characteristics of a target, a method of securing elliptically polarized output has been under study. The cross-polarized receiving arm shown in Fig. 2 has been used for transmitting, together with the conventional transmitting arm of the magic tee. This permits the simultaneous transmission of two orthogonal linearly polarized component waves; and one component of the reflected wave is received by the conventional receiving arm of the magic tee. Relative phase and amplitude of the two components of the transmitted wave are controlled by an attenuator and line stretcher so that a transmitted wave of arbitrary polarization may be obtained. In order to determine the polarization of the transmitter a wire was rotated about the beam axis of the horn and patterns of the received signal versus angle of rotation obtained. The polarization dumbbell of the transmitted wave may be obtained from these patterns by multiplying the received voltage at angle ϕ by the secant of ϕ, where ϕ is the angle between the wire and the direction of receiver polarization. Fig. 3 illustrates the pattern obtained when transmitting polarization is linear. The solid curve represents the theoretical variation, and the points represent the measured variation in return. Fig. 4 illustrates the pattern obtained for approximately circularly polarized output, and Fig. 5 illustrates the pattern obtained for an intermediate elliptically polarized wave. The sense of

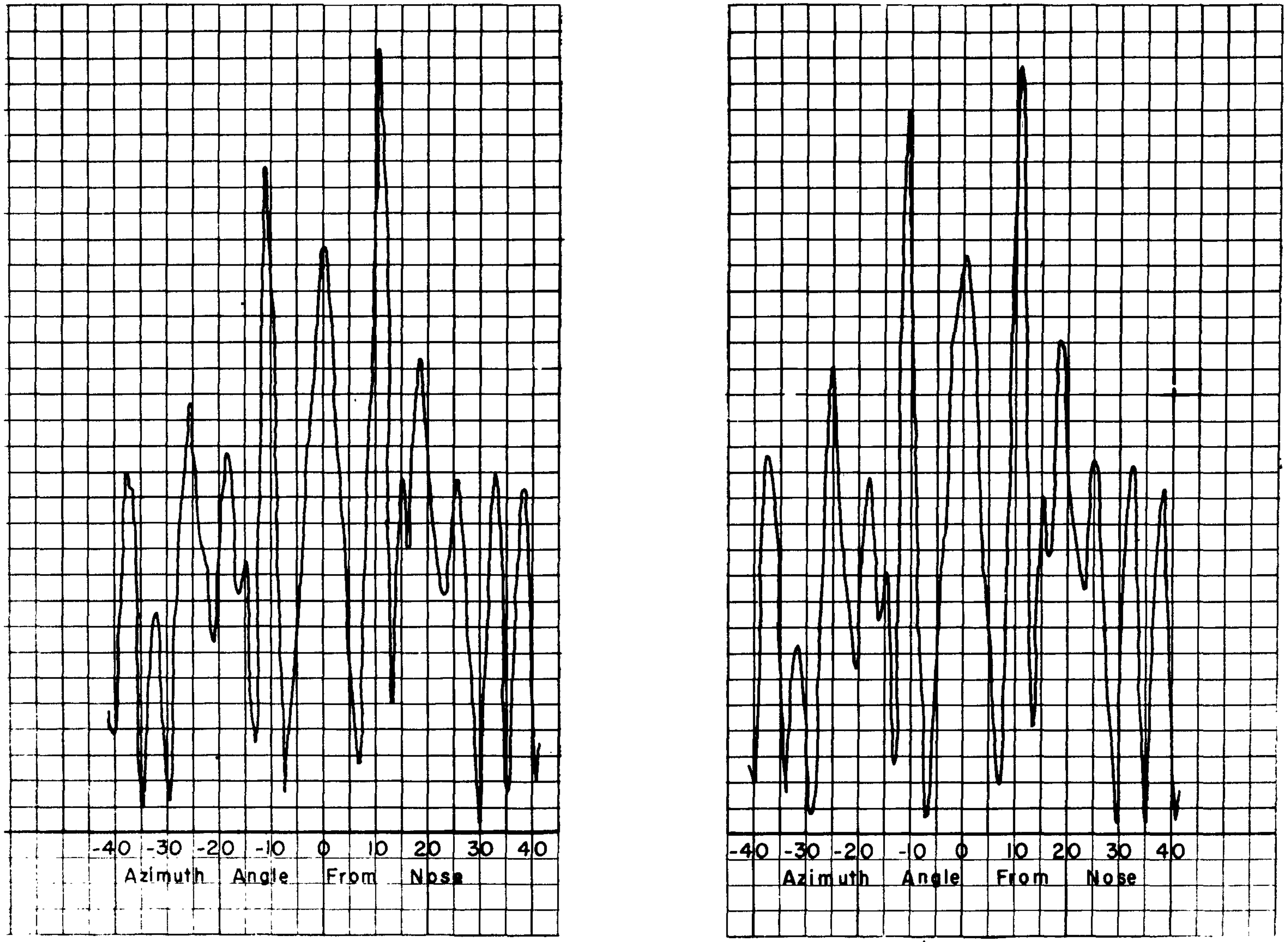

Fig. 1. Comparison of 9000-mc echo patterns obtained from 1/20-scale F-80 aircraft. Transmitting and receiving antennas horizontally polarized. Patterns taken two weeks apart

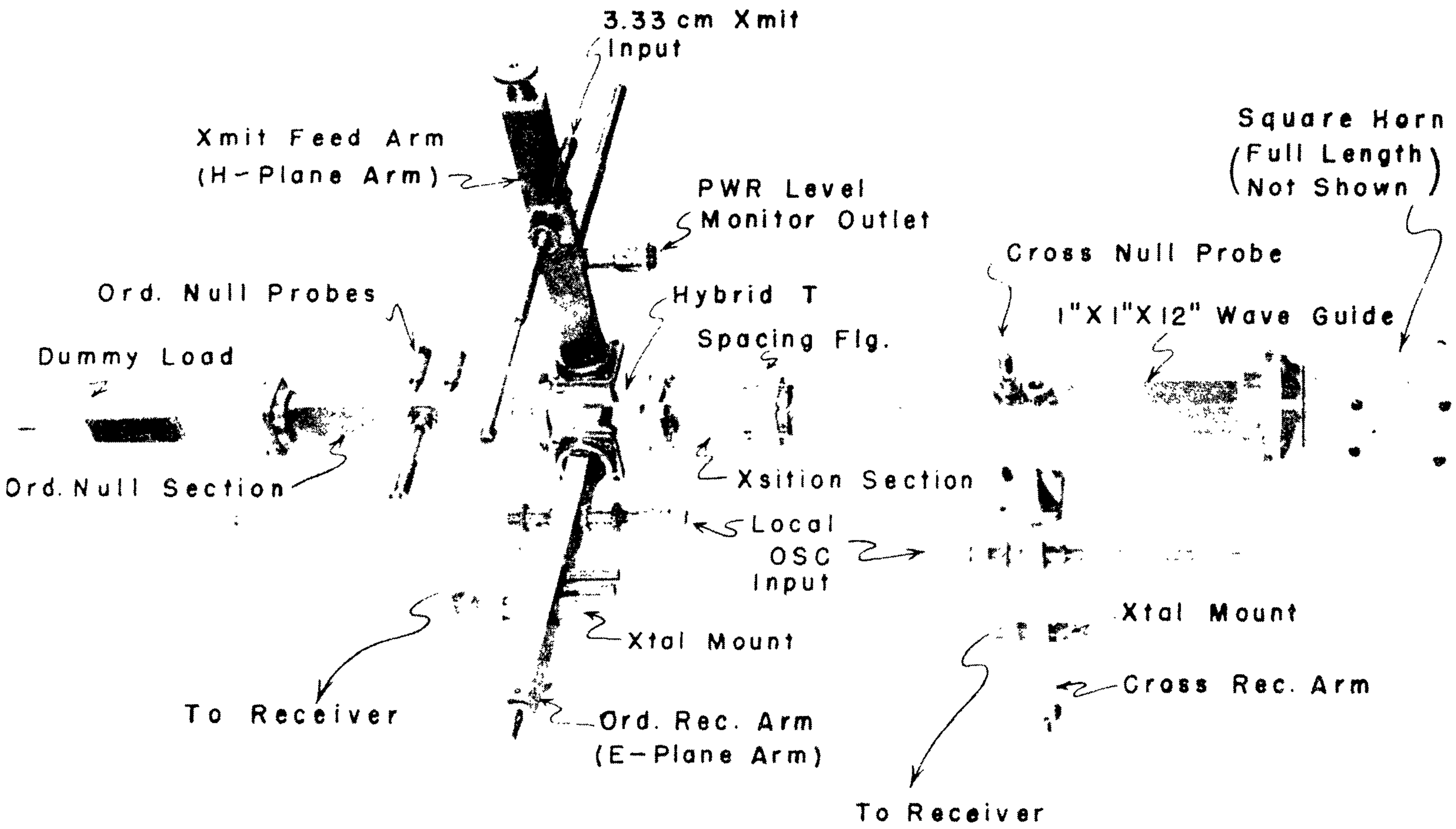

Fig. 2. Plumbing details of measuring assembly.

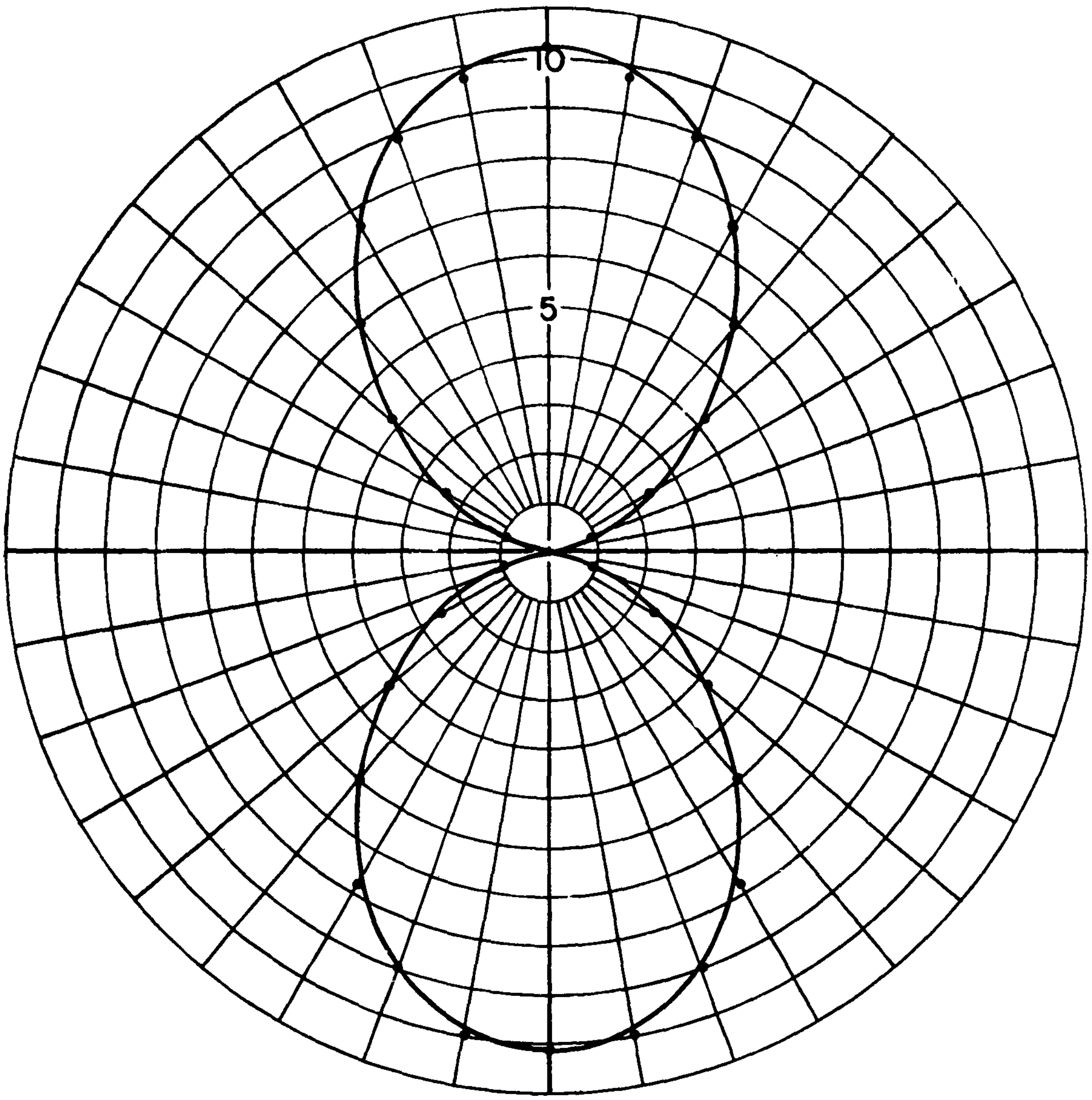

Fig. 3. Polar reflection pattern obtained by rotation of wire about axis of propagation of linearly polarized transmitting wave.

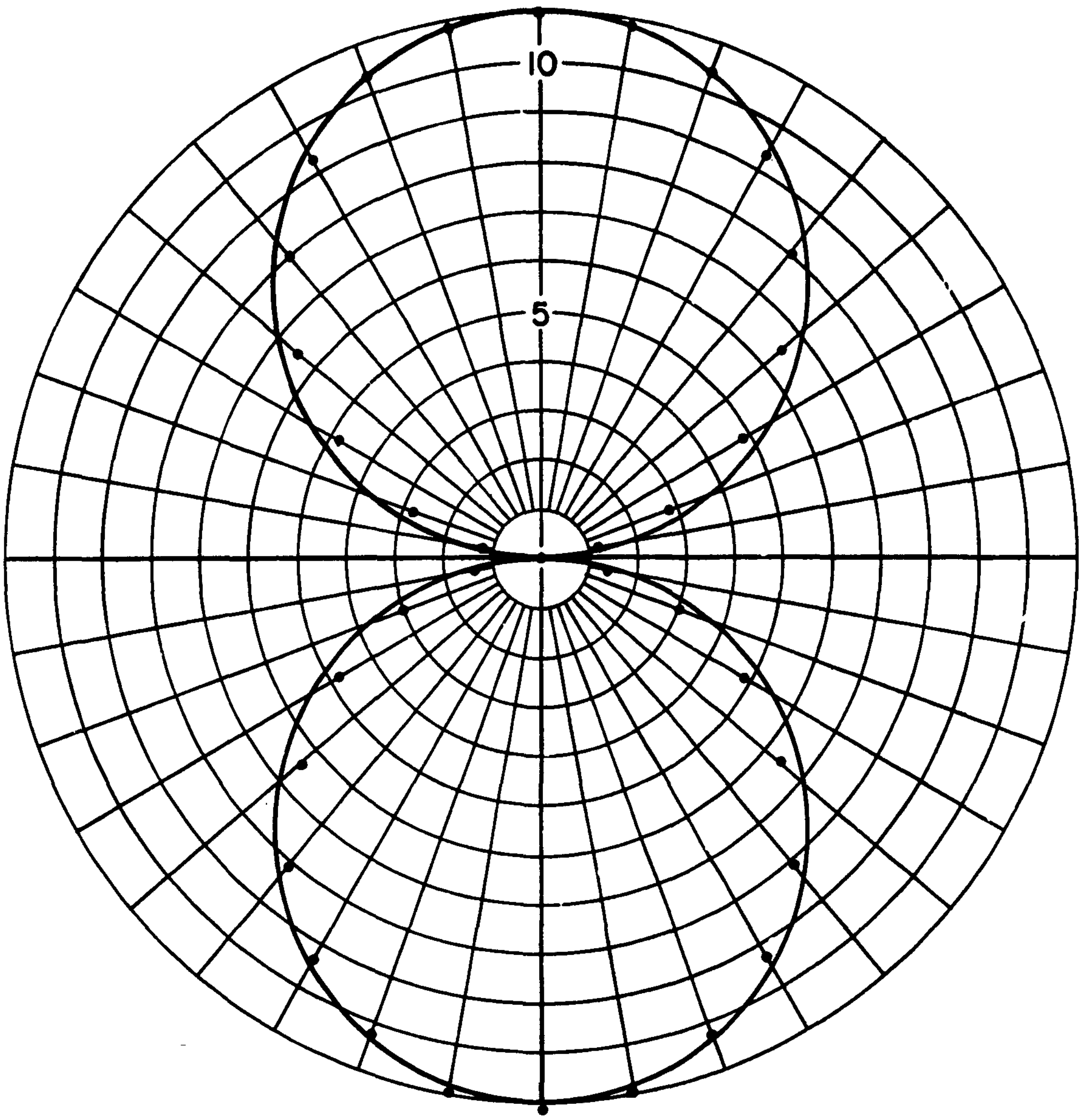

Fig. 4 Polar reflection pattern obtained by rotation of wire about axis of propagation of circularly polarized transmitting wave.

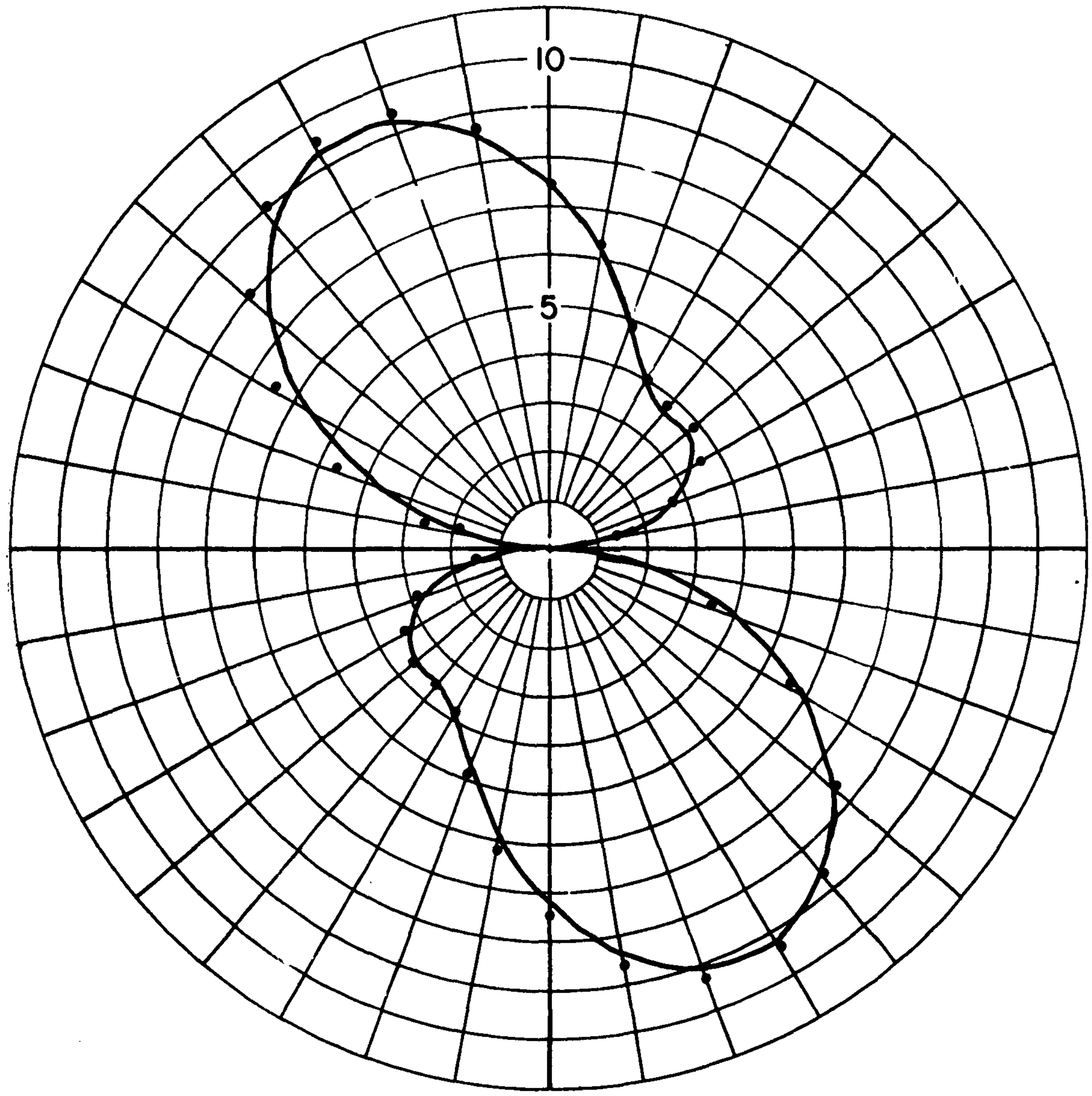

Fig. 5. Polar reflection pattern obtained by rotation of wire about axis of propagation of elliptically polarized transmitting wave.

the transmitting wave polarization may not be determined from these patterns, but special targets constructed from thin wires will be developed for this purpose.

The application of this technique to the determination of the target 10
polarization properties is of interest. If a target with scattering matrix[2]

$$\underline{A} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \tag{1}$$

is under study and the transmitting polarization is variable, with the receiving antenna linearly polarized in the ϕ direction, the received voltage is proportional to

$$Q = \left| (0 \quad 1) \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} h_\theta{}^t \\ h_\phi{}^t \end{pmatrix} \right| . \tag{2}$$

Now if the transmitting polarization is varied until the received voltage becomes zero,

$$0 = (0 \quad 1) \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} h_\theta{}^t \\ h_\phi{}^t \end{pmatrix} , \tag{3}$$

$$0 = a_{21} \, h_\theta{}^t + a_{22} \, h_\phi{}^t , \tag{4}$$

$$\frac{h_\theta{}^t}{h_\phi{}^t} = \frac{-a_{22}}{a_{21}} . \tag{5}$$

A unique transmitting polarization, defined by (5), yields zero received voltage. From a knowledge of the transmitting polarization which satisfies this condition the relative phase and amplitude of a_{22} and a_{21} may be determined. In the same manner, if the receiving antenna is polarized in the θ direction, the transmitting polarization which yields zero received voltage is given by

$$\frac{h_\theta^{\,t}}{h_\phi^{\,t}} = \frac{-a_{12}}{a_{11}} \quad . \tag{6}$$

Since $a_{12} = a_{21}$, the relative phase and amplitudes of the elements of the scattering matrix may be determined from a knowledge of the transmitting polarizations which yield zero received voltage for each of two orthogonal directions of linear receiving polarizations. The utility of this method is greatest when a_{12} is not zero, and a proper choice of directions of receiver polarization always insures this unless the scattering matrix is a scalar times the unit matrix. Such a scattering matrix may be measured directly with two linearly polarized echo measurements. This technique will be applied to the determination of the polarization properties of a target, as a check of linearly polarized echo measurements.

Considering a target with a plane of symmetry containing the line of 11
sight of a transmitting-receiving antenna, one immediately expects that a transmitted wave linearly polarized in the plane of symmetry would yield no orthogonal component in the reflected wave. This statement is proved in the appendix. Note the following statements verified in Progress Report 389-4:[2]

a. The maximum return for any fixed aspect of a target can be 12
achieved by using the same antenna for transmitting and receiving, provided an antenna of the proper elliptical polarization is chosen.

b. Two orthogonal reference elliptical polarizations may al- 13
ways be found for which a target scattering matrix becomes diagonal. One of these two polarizations will yield the maximum echo area.

Combining these statements with the introductory statement concerning 14
the symmetry dependence of cross-polarized return, the following theorem is obtained:

For any target with a plane of physical symmetry containing the 15
line of sight of a transmitting-receiving antenna, the maximum return for that aspect can be achieved by the use of linear polarization.

As indicated above, the theorem follows from statement (b) if a set 16.
of reference vectors can be found for which no orthogonal component exists in the reflected wave, i. e., the scattering matrix is diagonal in this reference system.

Consider a target located at the origin of a cartesian coordinate system with an antenna on the positive z-axis (see Fig. 6). The antenna height may be given in terms of ϕ and θ components parallel to the y- and x-axes, respectively. This reference system may also be rotated by any angle ψ about the line of sight and the new system denoted by primes using the same symbols. The received voltage developed in the antenna is proportional to Q, which is given by

$$Q = \left| (h_\theta \quad h_\phi) \begin{pmatrix} a_{11} & a_{12} \\ a_{12} & a_{21} \end{pmatrix} \cdot \begin{pmatrix} h_\theta \\ h_\phi \end{pmatrix} \right| , \qquad (7)$$

where a_{ij} are the elements of the scattering matrix referred to the unprimed system; h_θ and h_ϕ are the components of the antenna height. In the primed system Q is given by

$$Q = \left| (h_\theta' \quad h_\phi') \begin{pmatrix} \cos\psi & \sin\psi \\ -\sin\psi & \cos\psi \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{pmatrix} \begin{pmatrix} \cos\psi & -\sin\psi \\ \sin\psi & \cos\psi \end{pmatrix} \begin{pmatrix} h_\theta' \\ h_\phi' \end{pmatrix} \right| , \qquad (8)$$

or

$$Q = \left| (h_\theta' \quad h_\phi') \begin{pmatrix} a_{11}' & a_{12}' \\ a_{12}' & a_{22}' \end{pmatrix} \begin{pmatrix} h_\theta' \\ h_\phi' \end{pmatrix} \right| . \qquad (9)$$

Then the elements of the scattering matrix in the primed system 17
are

$$a_{11}' = a_{11} \cos^2\psi + 2\, a_{12} \sin\psi \cos\psi + a_{22} \sin^2\psi$$

$$a_{12}' = (a_{22} - a_{11}) \sin\psi \cos\psi + a_{12}(\cos^2\psi - \sin^2\psi) \qquad (10)$$

$$a_{22}' = a_{11} \sin^2\psi - 2\, a_{12} \sin\psi \cos\psi + a_{22} \cos^2\psi .$$

If two distinct planes of target symmetry exist, intersecting in the 18
line of sight of the antenna and forming an angle different than 90°, then the diagonal elements of the scattering matrix must be equal and the maximum return is obtained with any linearly polarized antenna. This follows from (10) if one chooses h_ϕ in one of the symmetry planes and h_ϕ' in the other. From the appendix, $a_{12} = a_{12}' = 0$, and from (9)

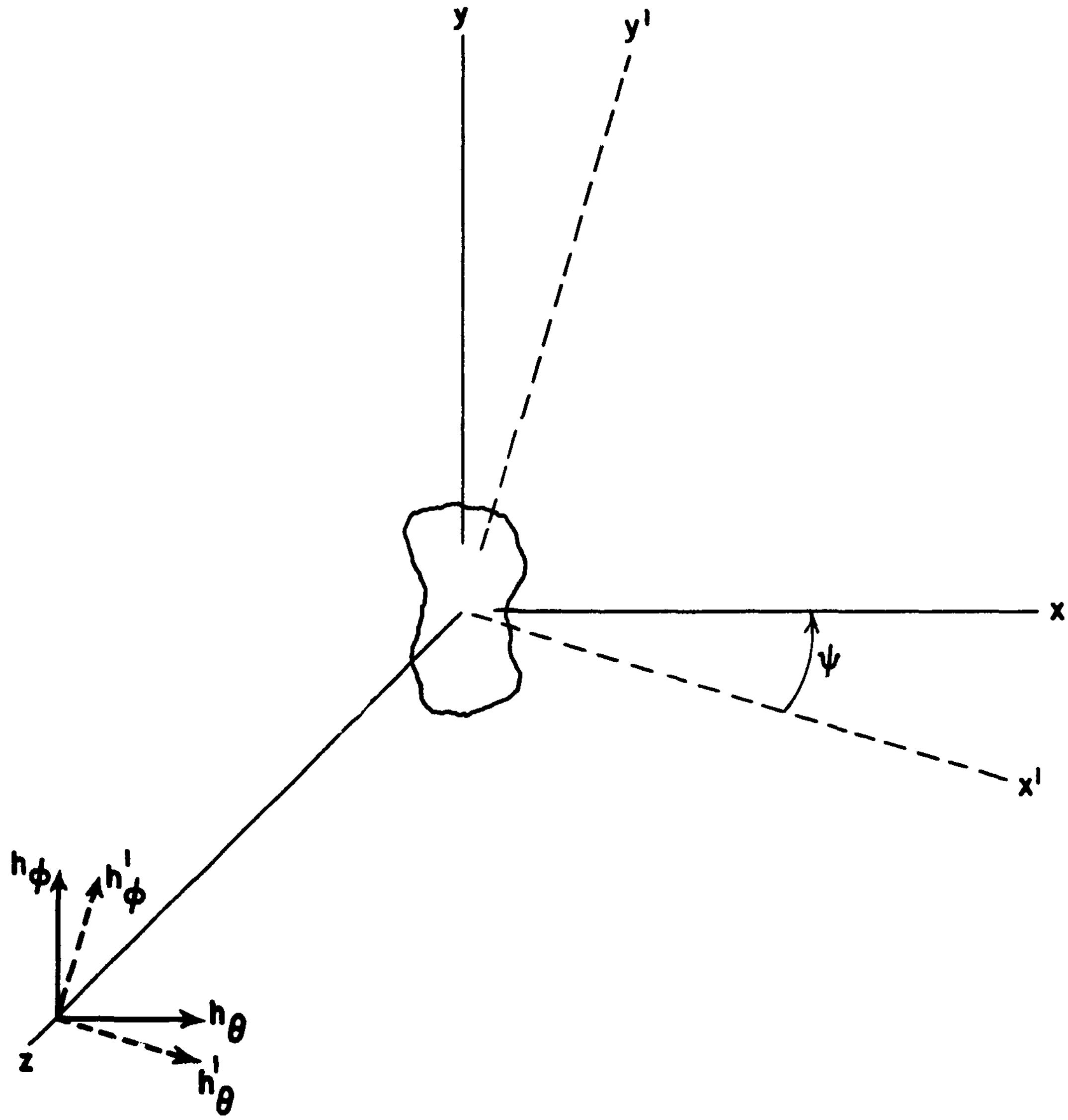

Fig. 6. Coordinate system illustrating rotation of linearly polarized reference frame.

$$a_{12}' = (a_{22} - a_{11}) \sin\psi \cos\psi = 0. \qquad (11)$$

Now $\sin\psi \neq 0 \neq \cos\psi$ for $0 \neq \psi \neq (\pi/2)$, hence $a_{22} = a_{11}$, and for any other angle of rotation ψ'' , the off-diagonal terms must be zero since

$$a_{12}'' = (a_{22} - a_{11}) \sin\psi' \cos\psi'' = 0. \qquad (12)$$

In general the planes of target symmetry may number from $n = 0$ to 19
∞ and are separated by an angle of π/n. Any rotation about the axis of intersection by a multiple of π/n leaves the target configuration unchanged. For directions in any of these planes the maximum return can be achieved with a suitable choice of linear polarization. In the particular case $n = \infty$ (a figure of revolution such as a shell) this is true for all aspects since each aspect has an associated plane of symmetry.

A triangular corner reflector sighted along the principal axis of 20
symmetry (broadside) is an excellent example of the case $n = 3$, or three planes of symmetry. There is no depolarization for any linear transmitting polarization, and the reflected power is the same for every transmitting polarization. Since this particular target reflects a circularly polarized wave with its sense reversed, the corner reflector or any symmetric modification thereof would not be suitable as a standard target for a common circularly polarized transmitting-receiving antenna combination. This is true of any target possessing three or more symmetry planes containing the line of sight.

The knowledge of these symmetry planes and their effects on the 21
scattering matrix for various polarizations will be particularly useful in designing targets for polarization studies.

In summary, the following has been shown for n planes of target 22
symmetry intersecting in the line of sight of a transmitting-receiving antenna:

a. The scattering matrix is diagonal if one of the linear base polari- 23
zations is chosen to lie in a plane of symmetry, and the maximum echo can be achieved for at least one of the base linear polarizations.

b. For more than two planes of symmetry the scattering matrix is 24
scalar for all linear base polarization vectors. Therefore, this target

aspect is "isotropic" in response to all transmitting polarizations.[2] Note that two symmetry planes separated by an angle other than 90° always imply at least three planes of symmetry.

D. CONCLUSIONS

Echo measurements of the 1/20-scale model F-80 have been facili- 25
tated by angling transmitting and receiving horn.

Alternative techniques for checking measurements with linear 26
polarization have been developed using variable transmitter polarization.

The cross-polarized and circularly-polarized returns of simple 27
targets may be analyzed qualitatively by the use of geometrical symmetry properties of the target. These considerations are important in the design of simple targets to serve as polarization standards.

E. PROGRAM FOR NEXT INTERVAL

Measurement and analysis of the polarization dependence of 9000-mc 28
return from the 1/20-, 1/15-, and 1/10-scale models of the F-80 aircraft at several aspects, and a range of aspects about the nose.

Theoretical and experimental investigation of the average polari- 29
zation properties of rainfall.

Experimental investigation of the "high spots" of target responsible 30
for major lobes in return patterns.

F. BIBLIOGRAPHY

1. Project Report 389-11, 16 December 1951, Antenna Laboratory, 31
The Ohio State University Research Foundation; prepared under Contract AF 28 (099)-90 with Rome Air Development Center, Griffiss Air Force Base, Rome, New York.

2. Project Report 389-4, 16 June 1950, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Contract AF 28 (099)-90 with Rome Air Development Center, Griffiss Air Force Base, Rome, New York.

G. APPENDIX

Effect of target symmetry on depolarized return

For any target aspect containing a plane of symmetry, a coordinate 32
system may be adopted such that the ϕ component lies in the plane of symmetry. Consider the following expression:

$$\begin{pmatrix} h_\theta & h_\phi \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{pmatrix} \begin{pmatrix} h_\theta \\ h_\phi \end{pmatrix} , \qquad \text{(A-1)}$$

which may be written as

$$\begin{pmatrix} h_\theta & h_\phi \end{pmatrix} \begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{pmatrix} \begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} h_\theta \\ h_\phi \end{pmatrix} , \qquad \text{(A-2)}$$

or

$$\begin{pmatrix} -h_\theta & h_\phi \end{pmatrix} \begin{pmatrix} a_{11} & -a_{12} \\ -a_{12} & a_{22} \end{pmatrix} \begin{pmatrix} -h_\theta \\ h_\phi \end{pmatrix} . \qquad \text{(A-3)}$$

From the form of (A-3) the central matrix is evidently the scattering matrix corresponding to an inversion of the target about the yz-plane and is given in terms of the original matrix elements. If the yz-plane is a plane of physical symmetry, one knows from the geometry that the scattering matrix remains the same after this inversion, and

$$a_{12} = - a_{12} = 0. \qquad \text{(A-4)}$$

Therefore this choice of reference frame results in a diagonal scattering matrix for a target with a plane of symmetry containing the line of sight.

H. IDENTIFICATION OF TECHNICIANS

MAN HOURS WORKED

	Dec.	Jan.	Feb.	March	Total
Alvin F. Buttler Technician	152	176	160	168	656
Robert A. Fouty Asst. to the Supervisor	19	22	20	17	78
Howard J. Hayman Machinist	---	---	---	31.5	31.5
Everett L. Huey Design Draftsman	76	88	80	84	328
Edward M. Kennaugh Project Engineer	152	176	160	84	572
Robert T. Law Model Maker	40	88	60	---	188
Jeanne C. McCoy Clerk-Typist	38	44	40	21	143
Dorothy McGinty Clerk-Typist	76	88	80	84	328
M. Frances Nichols Computer	76	88	40	42	246
Victor H Rumsey Supervisor	19	22	20	21	82
William M. Ryan Photographer	38	44	40	21	143
William J. Schwartz Clerk-Mechanic	19	22	20	21	82
Raymond W. Sloan Engineer	---	---	---	168	168

Louis L. Taylor Engineer	152	176	160	168	656
Peter D. Young Technical Assistant	---	---	20	21	41
Hourly					
Clayton C. Fletcher Design Draftsman	---	---	5	---	5
Weldon Mortine Clerk	69.5	28	---	---	97.5
TOTAL	926.5	1062	905	951.5	3845

NOTE: In submitting this report it is understood that all provisions of the contract between The Foundation and the Cooperator and pertaining to publicity of subject matter will be rigidly observed.

Investigator........E. M. Kennaugh........ Date..15 April 1952

Investigator........R. W. Sloan........ Date..15 April 1952

Investigator........Alvin F. Buttler........ Date..15 April 1952

Investigator........Louis L. Taylor........ Date..15 april 52

Investigator................................ Date....................

Supervisor........H. Rumsey........ Date..15 April 52

FOR THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION

Executive Director........Oram C. Woolpert........ Date..18 April 1952

W.L.H.